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Article

Comparative analysis of the diet of *Arctocephalus gazella* (Pinnipedia), at two localities of the South Shetland Islands, with emphasis on the fish component

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ABSTRACT. We studied the diet of non-breeding male Antarctic fur Seals *Arctocephalus gazella* (Peters, 1875) at two different localities of the South Shetland Islands: Stranger Point, King George Island/Isla 25 de Mayo and Duthoit Point, Nelson Island, by the analysis of 65 faecal samples collected in February 2012. Overall, Antarctic krill *Euphausia superba* (Dana, 1850) and fish were the main prey taxa followed by penguins and cephalopods. Myctophids were dominant among fish; *Gymnoscopelus nicholsi* (Gilbert, 1911) was the most important prey species at both sampling sites, followed by *Electrona antarctica* (Gunther, 1878) at Stranger Point and by the nototheniid *Pleuragramma antarctica* (Boulenger, 1902) at Duthoit Point. The relative similarity found in the dietary composition of fur seals from both locations suggest they might have been sharing common feeding areas. Our results were compared with those reported in the literature for different localities of the South Shetland Islands and the Scotia Sea region. The absence of formerly harvested demersal notothenioid species in the diet of fur seals may reflect the negative impact that commercial fisheries had on some fish populations and supports the importance of implementing long-term monitoring studies on the feeding habits of *A. gazella* in the area.

KEYWORDS. Antarctica, fish prey, trophic ecology, fur seal, commercial fishery.

RESUMEN. **Análisis comparativo de la dieta de *Arctocephalus gazella* (Pinnipedia), en dos localidades de las Islas Shetland del Sur, con énfasis en su componente íctico.** Se estudió la dieta de ejemplares macho no reproductivos de lobo fino antártico, *Arctocephalus gazella* (Peters, 1875) en dos localidades de las Islas Shetland del Sur: Cabo Funes/Punta Stranger, Isla 25 de Mayo/Isla Rey Jorge y Punta Duthoit, Isla Nelson; por medio del análisis de 65 muestras de materia fecal colectadas en Febrero de 2012. En general, el krill antártico *Euphausia superba* (Dana, 1850) y los peces fueron los taxa presa más consumidos, seguidos por pingüinos y cefalópodos. Entre los peces, los mictófidos fueron dominantes; *Gymnoscopelus nicholsi* (Gilbert, 1911) fue la especie más importante en ambos apostaderos, seguido por *Electrona antarctica* (Gunther, 1878) en Punta Stranger y por el nototénido *Pleuragramma antarctica* (Boulenger, 1902) en Punta Duthoit. La similitud hallada en la composición dietaria de los agrupamientos de lobo estudiados sugiere áreas de alimentación en común. Nuestros resultados fueron comparados con aquellos reportados en la literatura para diferentes localidades de las Islas Shetland del Sur y la región del Mar de Scotia. La ausencia de especies de nototenoideos demersales históricamente diezmadas en la dieta del lobo fino podría estar reflejando el impacto negativo que las pesquerías comerciales han tenido sobre algunas poblaciones de peces y enfatizar la necesidad de realizar un monitoreo a largo plazo de los hábitos alimentarios de *A. gazella* en el archipiélago de las Islas Shetland del Sur.

PALABRAS CLAVE. Antártida, peces presa, ecología trófica, lobo fino antártico, pesquería comercial.

In the food web of the Southern Ocean marine ecosystem, krill *Euphausia superba* (Dana, 1850) is a keystone species since it provides a direct link between primary producers and higher trophic levels (Loeb *et al.*, 1997). Fish also take a central position in this ecological network occupying a variety of niches, thus representing an important food source for a multitude of marine vertebrate species such as other fish, birds, whales and seals (Barrera-Oro, 2002; Mintenbeck *et al.*, 2012). In this context, the knowledge of the diet of top predators, such as pinnipeds, is fundamental to interpret their role in the food web and to provide information about potential competition for food resources with other predators and commercial fisheries (Daneri & Carlini, 1999; Osman *et al.*, 2004). Marine predators are considered effective samplers of fish, cephalopod and crustacean populations; the analysis of the indigestible prey parts they consume, *e.g.*, otoliths, carapaces and beaks is frequently used to infer predator foraging habits and provide information such as age and length distribution for these different prey taxa (Begg *et al.*, 2005; Goebel *et al.*, 2007; Negri *et al.*, 2016; Klemmedson *et al.*, 2020).

The Antarctic fur seal *Arctocephalus gazella* (Peters, 1875) has a widespread distribution in the Southern Ocean (Fischer & Hureau, 1988). Most of their breeding colonies occur mainly on islands south of the Antarctic Convergence, such as South Georgia, South Orkney, South Shetland, Heard and Kerguelen Islands, with the exception of Marion, Crozet and Macquarie Islands, which lie north of it (Reeves *et al.*, 1992). This otariid species was subjected to an extensive commercial exploitation during the nineteenth century which left it to the verge of extinction. Notwithstanding, a substantial recovery has been observed throughout the twentieth and early twenty-first centuries (Bonner, 1968; Aguayo & Torres, 1993; Hucke-Gaethe *et al.*, 2004).

Specifically, at the South Shetland Islands, fur seal colonies were subject of intensive sealing activities at the beginning of the 1820s, soon after the discovery of the archipelago, leading them to near extermination (Bengtson *et al.*, 1990). It was not until the 1960 decade when reproductive groups of *Arctocephalus gazella* were found at Livingston Island, Widow Islet and Elephant Island. Since early estimates this population has increased from a few dozens to over 21,000 individuals in 2002 (Hucke-Gaete *et al.*, 2004; Daneri *et al.*, 2019). Latest information for the same archipelago indicates that the population trend has been fluctuating since 2003, showing a decrease in 2008 when a census indicated a total of 14,200 individuals including 6,100 pups (SCAR-EGS, 2008). The South Shetland Islands also host many haul-out sites of nonbreeding male Antarctic fur seals. At Cabo Funes/Stranger Point within the Antarctic Specially Protected Area (ASPA) n°132, King George Island/Isla 25 de Mayo, every year from the end of January onwards, there is an influx of mainly juvenile and subadult male fur seals reaching peak numbers between March and April. Maximum numbers of nearly 2,000 individuals were recorded in the 2016 austral summer (Daneri *et al.*, 2019).

Studies of the feeding habits of *Arctocephalus gazella* have shown that krill *Euphausia superba*, various fish taxa, and to a lesser extent, cephalopods, constitute the bulk of its diet. However, there are substantial differences in the relative proportion of the prey taxa, according to the age and sex of the seals, as well as between seasons and different populations (Casaux *et al.*, 2003; Daneri *et al.*, 2005; Reid *et al.*, 2006; Hofmeyr *et al.*,2010). At the South Shetlands, most dietary studies reported that, during summer, the myctophids *Electrona antartica* (Gunther, 1878) and *Gymnoscopelus nicholsi* (Gilbert, 1911) constitute the dominant fish prey, followed, secondarily, by notothenioid species (Osman *et al.*, 2004; Ciaputa & Sicinski, 2006; Daneri *et al.*, 2008; Harrington *et al.*, 2016).

The South Shetland Islands-Antarctic Peninsula (FAO Statistical Subarea 48.1) was scenario of a commercial exploitation on krill and fish, that took place along the Southern Ocean since the 1960s (Kock, 1992). Of these resources, not krill but several finfish populations were seriously depleted. Heavy finfishing was carried out in the northern coasts of the northern most island of the South Shetlands, Elephant Island, in the period 1977-1980, but catches from the north of Livingston and King George Island / Isla 25 de Mayo and from Joinville-D'Urville Islands in the tip of the Antarctic Peninsula have also been reported (CCAMLR, 1986). While the myctophids were not exploited by the fishing industry, the marbled notothenia *Notothenia rossii* (Fischer, 1885) and the mackerel icefish *Champsocephalus gunnari* (Lonnberg, 1905) were the main targeted species, whereas the humped rock cod *Gobionotothen gibberifrons* (Longberg, 1905) was to some extent also taken in a directed fishery and as by-catch (Kock & Jones,2012; Marschoff *et al.*, 2012; Barrera-Oro *et al.*, 2017). Attempts to promote the recovery of the exploited species have been taken since the inception of the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) in 1982 by banning directed fisheries and establishing stringent by-catch limits. The Subarea 48.1 remains closed to any finfishing since the 1990/1991 season according to CCAMLR conservation measures (CCAMLR 1990; Barrera-Oro *et al.*, 2000).

Based on the analysis of scats of non-breeding male Antarctic fur seals from Stranger Point and Duthoit Point, both sites in the South Shetland Islands, the aims of this study were to: 1) determine their diet with emphasis on the fish species composition; 2) compare our results with previous dietary studies of this otarid species from the same area; 3) assess the potential/actual ecological interactions between fur seals and commercial fisheries in the South Shetland Islands. Furthermore, this is the first dietary report of *Arctocephalus gazella* for the locality of Duthoit Point.

MATERIALS AND METHODS

Samples were collected at the vicinity of Stranger point, King George Island/Isla 25 de Mayo (n = 50) (62°14'S; 58°40'W) and at Duthoit point, Nelson Island (n = 15) (62°19'S; 58°48'W) in February 2012 (Fig. 1). The method used in this study involved the collection of fresh faeces from male individuals of *Arctocephalus gazella* within the sub adult age group. Using this methodology, samples are easy to obtain and there is no requirement to capture and restrain animals (Reid, 1995). Once collected, each scat was individually bagged and stored frozen at -20°C in the laboratory until processing.

In the laboratory, each sample passed through a series of sieves of different mesh sizes (2.5 – 0.5 mm) under fresh running water and hard remains such as fish sagittal otoliths, cephalopod mandibles and crustacean carapaces were collected for identification and measurement. Prey remains were identified to the lowest possible taxonomic level using identification guides (Clarke, 1986; Hecht, 1987; Williams & McEldowney, 1990; Xavier & Cherel, 2009). When otoliths and mandibles were not present, fish bones and eye lenses and cephalopod eye lenses, from which specific identification is usually impossible, were recorded. Two samples from Stranger Point and three from Duthoit Point, contained no distinguishable remains and were therefore excluded from further analysis. The proportional frequency of occurrence (F%) was calculated for each main prey item identified (*e.g.*, krill, fish, cephalopods) as the number of scats containing a prey taxon divided by the total number of scats containing identifiable prey remains. Fish

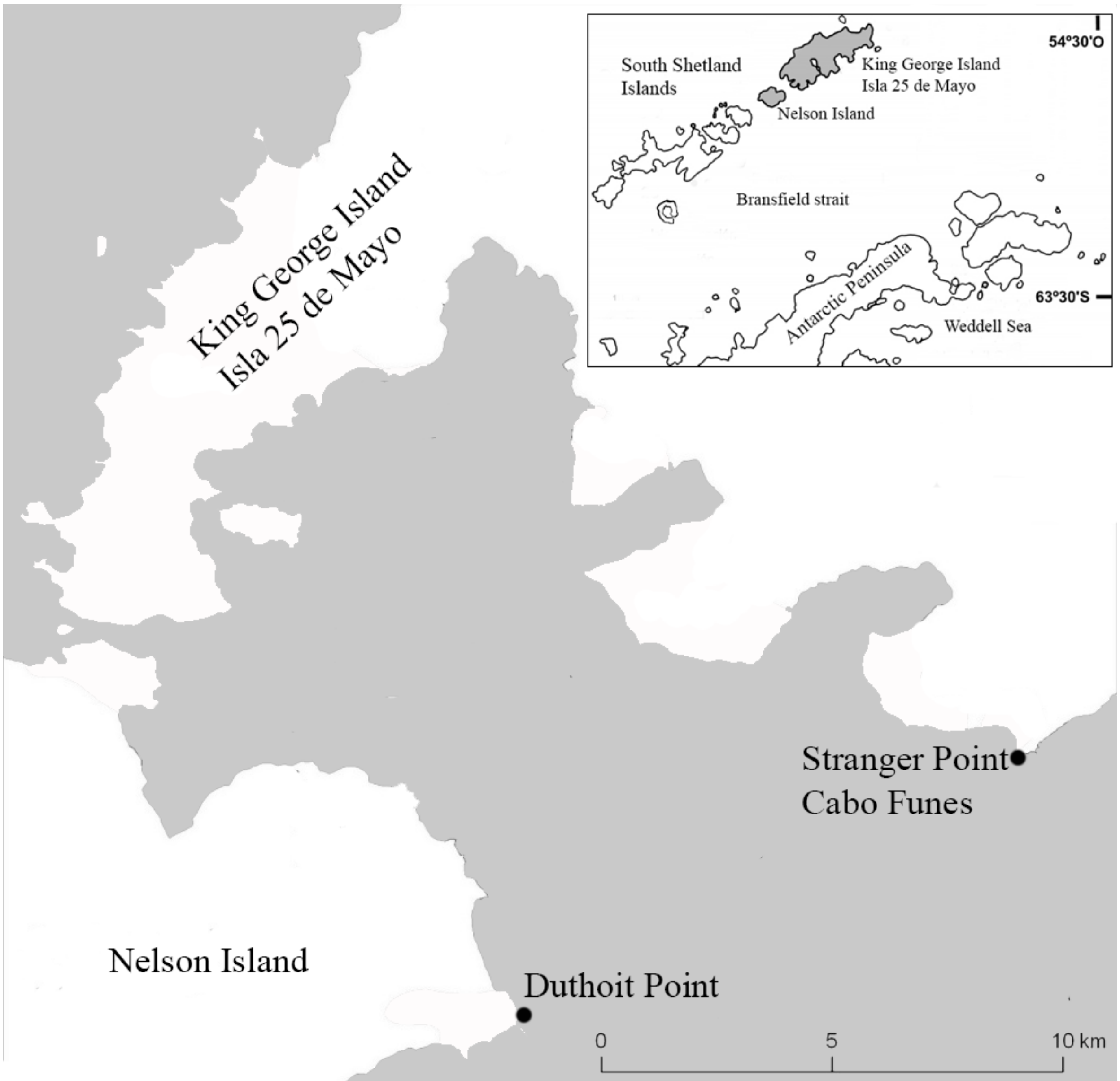

Fig. 1. The study area at South Shetland Islands: Stranger Point, King George Island/Isla 25 de Mayo and Duthoit Point, Nelson Island (modified from Malvé *et al.,* 2014 and Braun *et al.*, 2017).

otoliths were assigned to one of the three following groups according to the degree of erosion: 1) Good – little or no erosion; 2) Fair – some signs of smoothing on margins; 3) Poor – heavily eroded with rounded margins. A correction factor was applied to compensate for erosion (10% for group 1 and 20% for group 2) after Reid (1995). Heavily eroded items were often impossible to identify and therefore were discarded. Once classified, the otolith lengths were measured to the nearest 0.01 mm and the fish body length and mass were estimated using regression equations published in Hecht (1987) and in Williams & McEldowney (1990). The occurrence of each fish species identified in the diet was expressed as F% (frequency of occurrence), is the percentage of scats containing a fish species as a percentage of the total number of scats containing fish; N% (numerical composition) is the number of individuals of a fish species as percentage of the total number of fish in the scats; and W% (weight composition) is the weight of a fish species as percentage of the total weight of all the fish (wet weight) consumed. All three measures were combined to calculate the index of relative importance (IRI) (Pinkas *et al.*, 1971). In order to make the interpretation of the IRI easier, this index was expressed on a percent basis (IRI%) following Cortes (1997). A chi-squared test was performed to assess geographical variation in the frequency of occurrence of the main prey items consumed by fur seals. In addition, a nested ANOVA test was used to detect differences between sampling sites in the sizes of the main fish prey species preyed on by fur seals, with scats (random factor) nested in study locality (fixed factor).

RESULTS

Considering the scats of both locations combined, krill was the most frequent prey item, followed by fish, with an occurrence of 84.3% and 63.5%, respectively. Of lesser importance were cephalopods and penguins, which occurred, respectively, in 20.8% and 12.2% of scats (Tab. I). There were significant differences in the frequency of occurrence of these four prey taxa between the two sampling locations ($X^2_3 = 18.32$, $p < 0.01$).

A total of 210 otoliths were recovered from the scat samples (n = 127 Stranger Point, n = 83 Duthoit Point) at a rate of 2.65 and 6.9 otoliths per scat respectively. Overall, considering both sampling sites, the family of lanternfish Myctophidae was dominant, accounting for more than 80% of the otoliths found. Moreover, *Gymnoscopelus nicholsi* was the most important and dominant fish prey species, constituting, in average, over 80% in number and biomass of the total fish predated.

At Stranger Point, *Gymnoscopelus nicholsi* and *Electrona antarctica* were the most frequent prey species followed by the nototheniid *Pleuragramma antarctica* (Boulenger, 1902). At Duthoit Point instead, *E. antarctica* was the dominant prey in terms of frequency of occurrence, followed by *G. nicholsi* and *P. antarctica*. Channichthyid fish were either absent or scarcely represented (Tab. II). The estimated standard length of the fish ingested ranged from 66.0 mm (*E. antarctica*) to 177.3 mm (*P. antarctica*) (Tab. III). The estimated size frequency distribution of individuals of *G. nicholsi*, discriminated by locality, is shown in Fig. 2; those of *P. antarctica* and *E. antarctica*,where the data of the two sampling sites were combined due to the low number of specimens found, are represented in Figs 3 and 4 respectively.

There were not significant differences between locations in the sizes of *Gymnoscopelus nicholsi* preyed upon by fur seals (Nested ANOVA $p = 0.78$).

Tab. I. Frequency of occurrence of the food items recovered from scats of non-breeding male *Arctocephalus gazella* (Peters, 1875) at Stranger Point and Duthoit Point, South Shetland Islands, in February 2012. Sample sizes in parentheses.

Taxon	Stranger Point (n = 48)	Duthoit Point (n = 12)
Krill	77.1	91.7
Fish	68.8	58.3
Cephalopods	16.0	8.3
Penguins	8.3	33.3

Tab. II. Fish represented by otoliths identification (n = 210) in scats of non-breeding male *Arctocephalus gazella* (Peters, 1875), at Stranger Point and Duthoit Point, South Shetland Islands,expressed as percentage of frequencies of occurrence (F%), numerical abundance (N%), wet weight (W%), and index of relative importance (IRI%).

Fish taxon	Stranger Point (n = 48)				Duthoit Point (n = 12)			
	F%	N%	W%	IRI%	F%	N%	W%	IRI%
MYCTOPHIDAE								
Electrona antarctica	35.3	9.4	5.5	3.0	75.0	4.8	2.0	5.0
Gymnoscopelus nicholsi	94.1	86.7	92.0	96.2	50.0	79.5	80.1	78.9
CHANNICHTYIDAE								
Channichthyidae spp.	5.9	0.8						
NOTOTHENIIDAE								
Pleuragramma antarctica	23.5	3.1	2.5	0.8	50.0	14.5	16.9	15.5
Lepidonotothen nudifrons					25.0	1.2	1.0	0.5

Tab. III. Estimated standard lengths (mm) of the fish represented by otoliths identification in scats of non-breeding male *Arctocephalus gazella* (Peters, 1875) at Stranger Point and Duthoit Point, South Shetland Islands.

Fish taxon	Stranger Point (n = 48)		Duthoit Point (n = 12)	
	Mean ± SD	Range	Mean ± SD	Range
MYCTOPHIDAE				
Electrona antarctica	88.3 ± 10.4	75.4 - 107.9	88.1 ± 15.7	66.0 - 102.8
Gymnoscopelus nicholsi	138.8 ± 12.8	109.7 - 164.9	137.1 ± 13.3	106.3 - 161.8
CHANNICHTYIDAE				
Channichthyidae spp.				
NOTOTHENIIDAE				
Pleuragramma antarctica	153.5 ± 2.2	152 - 155.1	155.6 ± 9.6	143.6 - 177.3
Lepidonotothen nudifrons			104.4	

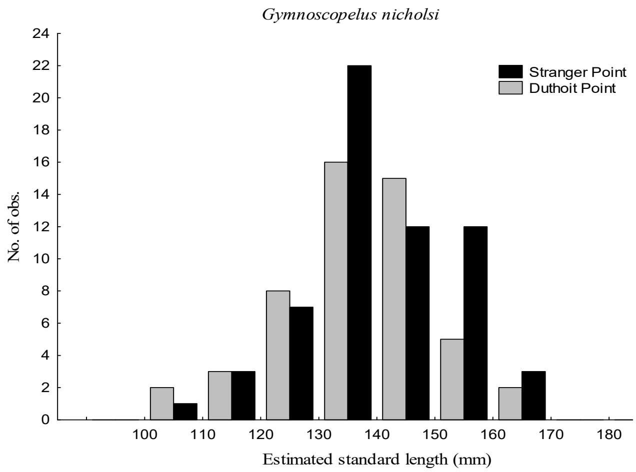

Fig. 2. Estimated standard length frequency distribution of *Gymnoscopelus nicholsi* (Gilbert, 1911), preyed on by Antarctic fur seals *Arctocephalus gazella* (Peters, 1875), at Stranger Point and Duthoit Point, South Shetland Islands, in February 2012.

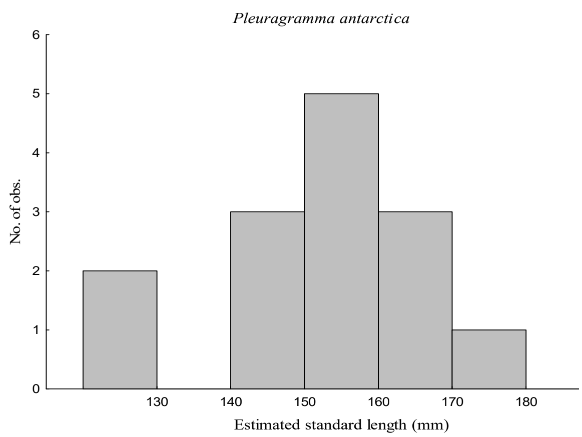

Fig. 3. Estimated standard length frequency distribution of *Pleuragramma antarctica* (Boulenger, 1902) preyed on by *Arctocephalus gazella* (Peters, 1875), at both sampling sites, Stranger Point and Duthoit Point, South Shetland Islands, in February 2012.

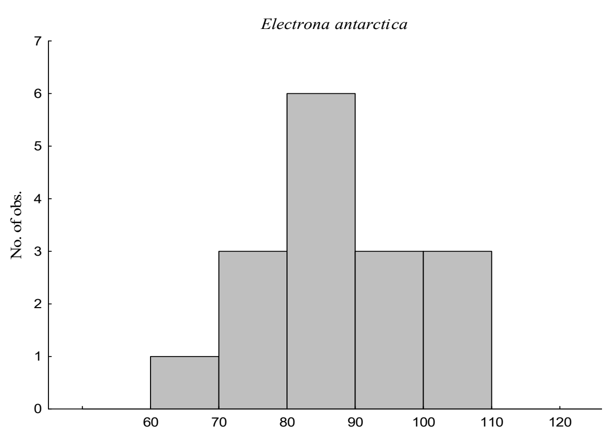

Fig. 4. Estimated standard length frequency distribution of *Electrona antarctica* (Gunther, 1878) preyed on by *Arctocephalus gazella* (Peters, 1875), at both sampling sites, Stranger Point and Duthoit Point, South Shetland Islands, in February 2012.

DISCUSSION

At both sampling locations krill and fish were the main prey item of fur seals in terms of frequency of occurrence. Cephalopods were the third prey in importance at Stranger Point whereas penguins were the third most consumed item at Duthoit point. Overall, the prey diversity found was similar to that described at other localities of the South Shetland Islands (Casaux *et al.*, 1998; Daneri & Carlini, 1999; Osman, 2004; Ciaputa & Sicinski, 2006; Harrington, 2016) showing that Antarctic fur seals commonly feed on locally abundant resources.

The fish component of the diet did not show substantial differences between sampling sites, with pelagic species of Myctophidae constituting the main prey. *Gymnoscopelus nicholsi* was the most important fish prey species and had the highest IRI% at both locations (Range: 78.9 – 96.2), followed by *Electrona antarctica* and *Pleuragramma antarctica*. These same species have also been reported as important contributors to the diet of Antarctic fur seals at other localities of the South Shetland Islands and Scotia Sea region (Casaux *et al.*, 1998; Daneri & Carlini, 1999; Osman, 2004; Ciaputa & Sicinski, 2006; Garcia-Garin *et al.*, 2020) and it is known that they are often associated with krill swarms (Williams, 1985; Fischer & Hureau, 1988; Williams & McEldowney, 1990). *Gymnoscopelus nicholsi* occurs over the continental shelf and is encountered near the bottom as well as in pelagic waters (Williams & McEldowney, 1990; Daneri *et al.*, 2008), whereas *E. antarctica* and the nototheniid *P. antarctica* are entirely pelagic (Gon & Heemstra, 1990).

In these fish species, sexual maturity is attained at total lengths of 160 – 180 mm in *Gymnoscopelus nicholsi*, 74 mm in *Electrona antarctica* and 125 – 140 mm in *Pleugragramma antarctica* (Gon &Heemstra, 1990; Burns *et al.*, 1998). Therefore, from the sizes estimated in this study we infer that fur seals preyed mainly upon mature stages of *P. antarctica* and *E. antarctica* and immature stages of *G. nicholsi.* Coincidentally, Osman *et al.* (2004) also found similar ontogenetic stages of *G. nicholsi* and *E. antarctica* individuals consumed by fur seals at Cape Shirreff. Additionally, the estimated lengths of the three most representative fish prey species identified in this study showed that fur seals preyed on a wide range of prey sizes, thus suggesting no selective size dependent behavior.

At Nelson Island, the only two dietary studies of *Arctocephalus gazella* were carried out at Harmony Point, on the western coast of the Island (Casaux *et al.*, 1998, 2004). In these works, the frequency of occurrence of krill was lower in comparison with our results, reaching, in average, 66.4% and 69.1% in the 1996/1997 and 2001/2002 seasons respectively. However, in agreement with our findings, penguins were the third most frequent food item and it was concluded that, when available, these birds are a potential prey for non-breeding male Antarctic fur seals. It is worth mentioning that a similar conclusion was drawn by Daneri *et al.* (2008) for Stranger Point fur seals, in the 1997/1998 summer season. Notwithstanding, it should be considered that the relatively high frequency of occurrence of penguin remains observed in the present study at Duthoit Point could be an artifact related to the small number of scats collected.

The similarities found on the feeding habits of fur seals from Stranger Point and Duthoit Point might be explained by the short distance between these sites (*ca.* 20 km), thus suggesting that individuals from both locations are probably using common feeding areas.

Specifically, for the fish component of the diet, none of the demersal species historically depleted at the South Shetland Islands in the late 1970s have been represented in the scats collected, even when they signify an energetically important prey (Barrera-Oro, 2002). Information on the present status of two of the historically commercially exploited species in the area indicate a very slow but a continuous recovery of *Notothenia rossii* and a still low recruitment in *Gobionotothen gibberifrons* (Kock *et al.*, 2007a; Kock & Jones, 2012; Barrera-Oro *et al.*, 2017). Besides over exploitation, it has been hypothesized that the lack of or slow recovery process of the mentioned species could be attributed to a number of factors such as continued illegal fishing, depletion of the pelagic larval and juvenile fish through by catch in the fishery for Antarctic krill, depensation owing to low population size and/or climate change (Marschoff *et al.*, 2012; Barrera-Oro *et al.*, 2017). Interestingly, while there are only two records of *G. gibberifrons* in the diet of *A. gazella* at the South Shetland Islands (Daneri, 1996; Casaux *et al.*, 2004), at South Orkney Islands this demersal fish species was a dominant prey during years of scarce pelagic prey availability (Casaux *et al.*, 2015) and was also present in the seals diet during the autumn period (Daneri & Coria, 1993). Moreover, it has also been reported as prey of fur seals from Hope Bay, western Antarctic Peninsula and South Georgia Islands (Reid, 1995; North, 1996, Reid *et al.*, 2006). Also, at this latter locality, a record of *N. rossii* in sub-adult male fur seals diet was reported (North *et al.*, 1983).

At South Georgia and South Orkney Islands, after the closure of the fisheries, an incipient recovery of stocks of *G. gibberifrons* is being observed (Casaux & Ramón, 2002; Belchier, 2013); whereas no commercial fin-fishing was carried out at Hope Bay. In agreement with the conclusions drawn by Reid *et al.* (2006), the absence of demersal fish species in the diet of fur seals at the South Shetland Islands may reflect the effect that the industrial fishery had on some populations of notothenioid species and suggests that this anthropogenic action impacted negatively on the seals which had to focus on an alternative prey resource.

Even though any fin-fishing at the South Shetland Islands area remains forbidden since 1990/1991 (CCAMLR, 2019), the waters north of this archipelago correspond to one of the most important krill-fishing regions in the Antarctic (Kock *et al.*, 2007b). Recent research has shown that male *A. gazella* foraging grounds overlap both in time and space with this fishery (Lowther *et al.*, 2020). Since fur seals strongly depend on krill as one of their main food sources, a potential competitor such as the commercial fishery could have detrimental effects on their survival. Furthermore, Antarctic fur seals have the potential to provide a great deal of information about the relative abundance and distribution of fish stocks. Therefore, we highlight the importance of implementing a long-term monitoring program on the diet of fur seals at the South Shetland Islands, in order to assess the potential/actual overlap between seals and krill fishing activities in the area, detect the existence of common feeding areas for seals from different locations of the archipelago and monitor the ecological impact of fishing operations on the trophic behavior of *Arctocephalus gazella*.

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